Drivers' behavioural reactions to unexpected events

Influence of workload, environment and driver characteristics

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Contents

Abstract

Many subtasks are relevant simultaneously when driving at urban intersections. Advanced Driver Assistance Systems (ADAS) can support the driver in this complex task. For a well-guided development and evaluatoin process of ADAS, insight into how different driving tasks influence each other is needed. Earlier research has shown that the interaction between different subtasks is changed by unexpected events. A driving simulator experiment was conducted to determine how gender, workload and event urgency influence this. Participants' reactions to two unexpected events were measured. Participants temporarily changed their driving behaviour in reaction to the event. Urgency of the event increased this effect; workload changed the length of adjustments to the event. An interaction effect was found between workload and urgency: participants with high workload drove smoother, unless urgency of the unexpected event reached a threshold. No influence of gender was found.

Keywords

Behavioural adaptation, workload, gender, levels of the driving task

1 Introduction

Urban driving is a complex task with many simultaneously relevant subtasks. Urban intersections establish challenging situations for drivers in this sense, as can be concluded from crash data: 38.5% of all Dutch traffic accidents leading to injuries in 2007 occurred at urban intersections (SWOV, 2008). Urban driving involves not only the correct use of vehicle controls, but also planning tasks and decisions about why, where and when the driver wants to drive. The driver has to take the correct turns, avoid collisions with other vehicles and keep an appropriate distance to vulnerable roads users. Next to this primary task of driving, the driver nowadays is confronted with many secondary tasks that take up a certain level of attention, such as talking on a mobile phone, interacting with music devices (such as a radio or MP3 player) or handling a navigation system. These tasks might interfere with the primary driving task (e.g., Brookhuis et al., 1991; Chisholm et al., 2008). This requires a wide range of skills, attention and goal management. The complexity of the driving task directly becomes clear when looking at student or novice drivers: all subtasks are new and require full attention, and juggling all these tasks simultaneously seems almost impossible to do. After practice, many tasks can be performed in an almost automatic way. Nevertheless, still many tasks are relevant simultaneously. Sometimes, this complexity leads to unsafe situations, or uncomfortable driving situations.

The development of Advanced Driver Assistance Systems (ADAS) can be a positive boost for the attempts to make driving safer and/ or more comfortable. ADAS can support drivers in their driving tasks, for instance by giving information that they might lack, by warning them that the current situation or an upcoming situation might be unsafe or difficult, or by taking over (part of) the driving task, either overrulable or autonomously. Applications of these ADAS are numerous: from Advanced Cruise Control systems (ACC) to Intelligent Speed Adaptation (ISA), and from forward collision avoidance systems to red light warnings. However, while the goal is to relieve the driver of part of his driving task, the driver’s needs are not always the focus of the designing process. Many ADAS developments are technology-driven. Furthermore, in many cases it is uncertain how the ADAS user will react to the system. When adding a new system to the human–vehicle interaction it changes the whole driving task, and might therefore change the way drivers perceive and perform their task. This behavioural adaptation may be positive, for instance when drivers can focus more on what is important when they are supported in certain subtasks, but in certain cases it brings about changes that are unexpected and unwanted. A well-guided process of development and evaluation of ADAS is a very important step towards safer driving.

In this paper, we present the results of a driving simulator study which gives insight into the structure of the driving task at intersections, and the factors which might have an influence on this. Insight into task handling is a first step in the development of ADAS, since a basic understanding of drivers’ upcoming actions and the way these are handled is crucial for many types of driver support.
We determined how an unexpected situation can temporarily influence certain driving tasks by means of a driving simulator experiment. This paper describes the influence of the level of workload, urgency of the unexpected event, and gender, on this influence. We will first elaborate on what is already known about the structure of the driving task and the interaction between different subtasks. Next, we will discuss

which factors might have an influence on the interaction between different subtasks of driving. Our simulator experiment and the experimental results will be described in the subsequent sections.

2 Background

2.1 Structure of the driving task

Almost all subtasks in driving influence other tasks by the outcome of their actions. Some tasks, such as deciding when and where to drive, might take place over a long time period, while others, such as sudden braking or a glance in the rear-view mirror, often take less than a second. Michon (1971) described this interaction between different types of subtasks in a hierarchical three-layer model of the driving task. The three layers are the strategic level (with route choice and travel goal), tactical level (with interaction manoeuvres with both the environment and other road users) and the operational level (with vehicle controlling tasks). These task levels are often active at the same time, and they influence each other. At intersections, route choice, interaction manoeuvres and control tasks are all important at the same time. Some task goals may be determined by the outcome of other subtasks. For instance, when a certain route has been chosen, the driver has to make the turns according to this route and therefore control the vehicle to make the appropriate moves. This is called top-down influence between the levels of the driving task: higher level tasks determine how and when lower level subtasks will be performed. Top-down influence generally takes place during normal driving; Michon (1971) calls this process of task level interaction *anticipation*. On the other hand, bottom-up influence can also occur – this means that lower level tasks influence the goals of higher level tasks. This interaction, also called *compensation*, is invoked by unexpected situations, because unexpected situations can lead to a higher priority for lower level tasks when they have to take over to guarantee safety or when the original task can not be performed successfully.

2.2 Factors which might influence the bottom-up interaction between driving tasks

A number of factors might have an influence on how and when bottom-up interaction between driving tasks occurs and becomes apparent.

Firstly, cognitive workload has a certain impact on driving performance, which can be either positive or negative. For instance, drivers experiencing higher workload can adapt their safety margins (Dragutinovic et al. (2005) give an overview), and reaction times can increase significantly (e.g., Brookhuis et al., 2001; Brookhuis et al., 2005). Any task which requires a certain amount of attention or concentration puts workload on the available cognitive capacities of the driver. Driving in itself brings along with it a certain level of workload, comprised of physical, visual and cognitive load. Secondary tasks can interfere with the main goal of driving safely. Recent research shows that the type of workload that is added to the primary task of driving has an impact on the level of interference with the driving task, with cognitive load interfering mostly with cognitive driving tasks (Baumann et al., 2008). When experiencing an unexpected event, the driver will temporarily switch from normal driving to compensatory driving actions. Workload might play a role in this switch,

for instance when decisions have to be made or when attention is needed for compensatory behaviour.
Secondly, driver characteristics play an important role in driving. Driving style, age and gender might influence how drivers perceive their world, their task and the risk of their actions. These characteristics might also influence how drivers react to an unexpected event. Hole (2007) gives an overview of studies reporting differences between men and women and between different age groups.
Thirdly, different types of unexpected events can invoke different compensation actions, which in turn can influence different subtasks for different amounts of time. Turning the steering wheel might have a different effect than having to brake suddenly, not only in the very short term but also some time after the event, in which drivers temporarily adapt their driving behaviour to the unexpected event encoutered.
Finally, not only the type of event but also the urgency of it may play an important role in the reactions to it. Drivers might react differently to a dangerous event from an event which is unexpected but not at all risky. The relation between the urgency of the event and drivers' reactions to an unexpected event is unknown, but might be crucial for understanding urban intersection driving.

2.3 Measuring driving behaviour and workload

Drivers' reactions to unexpected events can best be measured by using a driving simulator, since the urgency of different events can be controlled and compared, almost all operational and tactical tasks can be recorded, and it is a safe way of studying risky driving maneuvres. Real world observations have the disadvantage that it is difficult, if not impossible, to organize the same unexpected event for each participant and to vary the urgency of these events, not to mention the ethical issues involved in willingly putting participants at risk. It is extremely difficult to explicitly answer questions about more or less automatically performed driving tasks, so questionnaires were also not a valid tool for the research questions at hand.

In order to determine how workload influences the interaction between levels of the driving task, workload can be varied by giving drivers one or more assignments next to the primary driving task. When determining the influence of workload, one also has to determine how workload varied between and within drives. This can be done by self-report measures, physiological measures, or by the Peripheral Detection Task (PDT).
Self-report measures, such as the NASA Task Load Index (NASA-TLX) questionnaire (Hart and Staveland, 1988) give insight into the workload felt by drivers. This questionnaire measures workload in human-computer interaction, and can be used for many interaction tasks, such as driving. After performing a task, participants give a subjective rating of experienced workload on six rating scales: Mental Demands, Physical Demands, Temporal Demands, Own Performance, Effort, and Frustration (Hart and Staveland, 1988). The main disadvantage of self-report measures is that objective measurements are difficult (Van Winsum and Hoedemaeker, 2000). Also, only an overall rating of workload over a whole experiment can be given, so focus on specific areas or time periods within an experiment is not possible when using the NASA-TLX.
Physiological measures, such as heart rate or heart rate variability, can also be used to measure workload. An important advantage of many physiological measurements is their unobtrusiveness (De Waard, 1996), although this does not go for all types of

physiological measurements. However, they require complex interpretation of results, and may reflect emotional strain and physical activity (Jahn et al., 2005).
The PDT is based on the fact that visual attention narrows as workload increases (Van Winsum et al., 1999). Participants wear a headband on their head, with a Light Emitting Diode (LED) in their peripheral field which lights up randomly every 3 to 5 seconds. Participants have to press a switch attached to their index finger as soon as they see the LED signal. Response time is measured. As workload increases, response time and the chance of missing a signal also increases. The PDT has been shown to be reliable to the demands of the driving task (Van Winsum et al., 1999) and also sensitive to peaks in workload (Jahn et al., 2005).

3 Aim and research questions

With knowledge about how subtasks at different levels interact and insight into the processes that underlie behavioural adjustments to unexpected events, we can gain more insight into behavioural adaptation to ADAS and determine when and in what way a driver needs to be supported in his task. Longitudinal compensation on lower-level tasks (compensation after an uexpected braking event) influences a number of higher-level tactical tasks, such as lateral acceleration and intersection approach speed pattern (Schaap et al., accepted). But this bottom-up interaction between the operational and tactical levels of the driving task may also be influenced by other factors, such as the type of event encountered, driver characteristics, workload or urgency of the unexpected events. The type and urgency of the unexpected event might lead to more extreme reactions. Cognitive workload might interfere with the driver's ability to interpret the current situation and form decisions about actions to take (Recarte and Nunes, 2003). And gender can have an influence on general driving style and sensation seeking behaviour.
We therefore investigated a number of factors which might influence the way drivers respond to unexpected situations.

We conducted a driving simulator study that investigates the interaction between subtasks within the driving task. We measured the effects of two unexpected events on driving behaviour, to see in which way the outcome of certain actions influenced other subtasks within the driving task. The study also focused on three situational factors and one driver characteristic which might have an effect on this interaction, namely the type and urgency of the event, the level of cognitive workload, and gender of the driver.

The research questions concerning the aspects of interaction between the levels of the driving task are:

- To what extend do different types of unexpected event have an influence on driving after the event?
- To what extend does additional cognitive workload have an effect on the influence between subtasks of driving?
- To what extend does the urgency of an unexpected event change the influence between different subtasks?
- To what extend does gender of the driver have an effect on the influence between subtasks of driving?

4 Method

4.1 Participants

Our analysis was based on complete data sets of 39 subjects who participated in the experiment. They were between 23 and 60 years old, had their driver's license for five years or more and drove 7,000 kilometres or more annually. The average age of the 39 participants was 41 years (standard deviation 13, minimum 23, maximum 60); 26 participants were male, 13 female.

4.2 Data measurement

The experiment was performed in a driving simulator of TNO Human Factors (Feenstra and Hogema, 2007), a fixed-based driving simulator with manual transmission (Figure 1). The car was a left-seated Volkswagen Golf 4 mock-up. Participants controlled the driving simulator by means of normal vehicle controls. The road environment and other road users were projected on three screens in front and to the side of the simulator. These screens had a total horizontal field of view of 180° and the total vertical field of view of 45°. The review mirror was projected on the front screen, at the location where one would normally look into the review mirror.

Figure 1: TNO fixed base driving simulator

The experimental environment was optimized by means of realistic environment projection, sound effects (engine, wind), and natural behaviour from other road users, based on the driver modules in ST Software (ST Software, 2008).

In order to determine the participants' workload during driving, participants had to perform the Peripheral Detection Task (PDT) (Van Winsum et al., 1999). A LED light, mounted on a headband in front of the driver, was shown to the participants randomly every 3 to 5 seconds (Figure 2a). Participants had a small switch attached to their index finger, which they had to press every time they saw the LED light (Figure 2b). The manual transmission in the simulator required the participants to take their right hand away from the steering wheel at certain times, due to which they could not press their right index finger against the steering wheel whenever they saw the LED light appear. In order to register all reactions correctly, the switch was therefore placed on the index finger of the left hand. If a participant did not respond to the LED light for 2 seconds or more, this was registered as a missed signal. Workload was determined by measuring PDT reaction times and the number of missed signals.

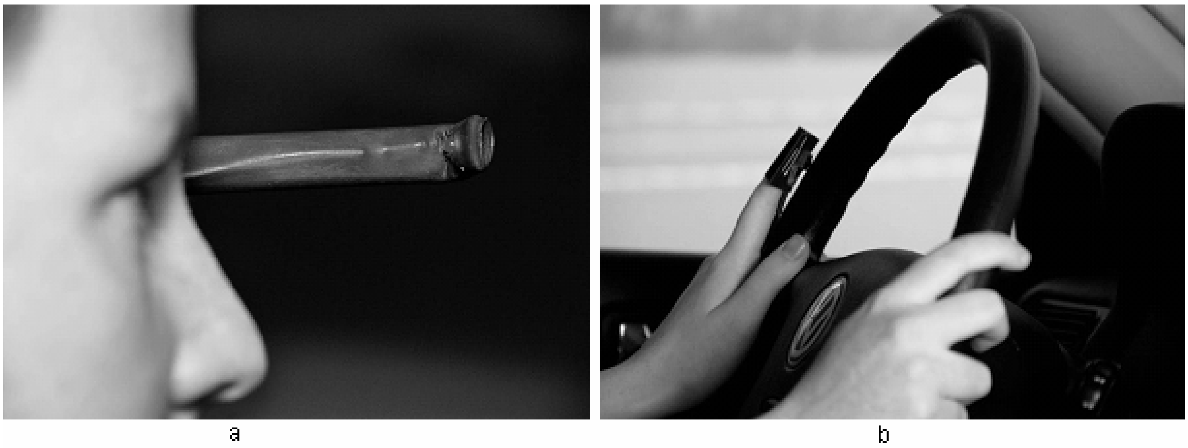

Figure 2: Peripheral Detection Task: (a) Headband with LED light and (b) Switch on index finger

4.3 Experimental design

An urban layout was simulated with twenty four-way intersections. Subjects were instructed to drive with a maximum speed of 50 km/h and give priority to traffic coming from the right, according to Dutch traffic regulations. They had to go straight on each intersection. The infrastructure was similar at each intersection, and the other road users always behaved similarly. A lead car drove in front of the subject the whole time. This vehicle slowed down when the subject fell too far behind, and speeded up when the subject came too close. This way, the lead distance was always between 18 and 48 meters from the simulated car. When the participant was approaching an intersection, a car coming from the right always crossed the intersection first. The participant and a lead car then reached the intersection, and a car from the left yielded and crossed after they had passed the intersection.
The experiment consisted of two event drives and two reference drives. In the reference drives, participants only drove on standard intersections, setting their expectations about the situations to come. In one event drive, an unexpected event happened: the lead vehicle suddenly braked. In the other event drive, the car approaching from the left suddenly accelerated and did not appear to give priority to the participant, in contrast with Dutch regulations. Both events had three event levels: mild (the lead car stopped braking when the participant was more than 30 metres away and the accelerating car would slow down if the participant was more than 10 metres away from the intersection), medium (the lead car stopped braking when the participant was between 18 and 30 metres away and the car from the left slowed down when the participant was 6 metres from the intersection) and hard (the participant was closer than 18 metres to the lead car and the car from the left braked when the participan had reached the intersection). This definition of event urgency was based on the fact that vicinity to a car driving a collision course has a direct relationship with the risk of a conflict and TTC. The order of the drives with the unexpected events was balanced among participants to eliminate possible learning effects. 13

participants encountered two “mild” events, 13 the “medium” events, and 13 encountered the “hard” events.

Half of the participants were furthermore given an additional, cognitive task, to determine the effect of cognitive load on the influence between the levels of the driving task. Table 1 shows the different tasks for each drive.

Table 1: Counting task for participants with additional task

Drive	Starting number	Subtracting number
Drive 1 – Reference drive	851	4
Drive with braking lead car	735	6
Drive 3 – Reference drive	800	7
Drive with accelerating car from left	900	8

Participants with a counting task were asked to continuously perform their assignment and were encouraged to go on with their task after several seconds of silence. They could give their final answers at their own pace, ensuring that all participants were equally challenged.

Two levels of cognitive workload (no additional task and additional task) and three levels of urgency (mild, medium and hard) combine to 6 event conditions. After each drive, participants were given a break and a questionnaire, with questions related to simulator sickness, the predictability of the driving task and the level of difficulty of the PDT. For the participants with the counting task, additional questions were asked about the level of difficulty of this task, and whether it had influenced the participant’s way of driving.

4.4 Analysis

Our analyses were done by means of a Repeated Measures ANOVA (Analysis of Variance). We studied main effects and interaction effects. The statistical significance level was set at .05.

The following between-subject factors were studied:

- Additional workload (2): with or without additional task
- Urgency (3): Mild, medium, hard (classifications were explained in Chapter 4.3)
- Gender (2): Male, female

The following within-subject factors were studied:

- Drive (3): reference drive, drive with braking lead car, drive with accelerating car
- Intersection (8): intersections before, during and after the unexpected event

5 Results

5.1 Expectations and workload

The expectations of the participants were tested both by studying learning effects in their driving behaviour (pointing to habituation), and by examining their answers to selected questions of the questionnaire. In this way, we were able to draw conclusions about whether the unexpected braking situation was actually seen as unexpected. Analyses show that this was indeed the case (Table 2).

Table 2: Learning effects and expectations of participants

Variable	Effect	F-value	p-value
Average speed	Drive	$F(3,99)=12.08$	$p < .001$
Standard deviation of speed	Drive	$F(3,99)= 30.241$	$p < .001$
Answers to questionnaire	Drive	$F(3,99)= 4.14$	$P < .010$

Average driving speed increased with experience, as a result of the participants' knowledge of what to expect. Furthermore, the standard deviation of the driving speed decreased significantly, specifically during the first part of the experiment. This supports our expectation that participants were getting used to the standard intersections during the first experimental drive. Also, the answers to the questionnaire revealed that the reference conditions were seen as significantly more predictable and expected than the drive with the unexpected event.

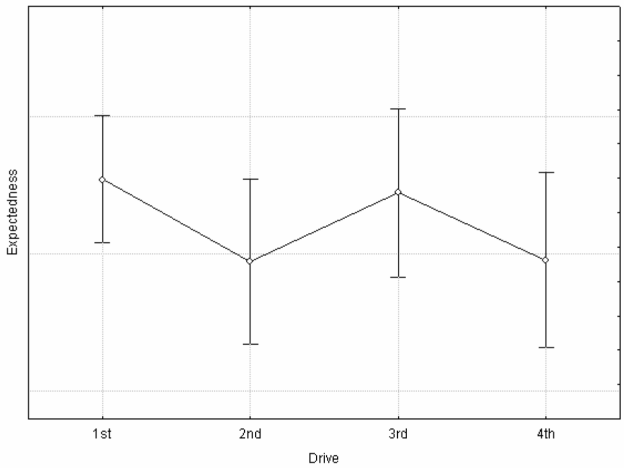

Figure 3: Predictability of each drive, based on answers to the questionnaire

The additional task significantly increased both the reaction times to the PDT ($F(1,29)= 54.725$, $p < .001$) and the number of missed signals ($F(1,33)= 34.873$, $p < .001$). This confirms our claim that the additional task increased the cognitive workload of the drivers.

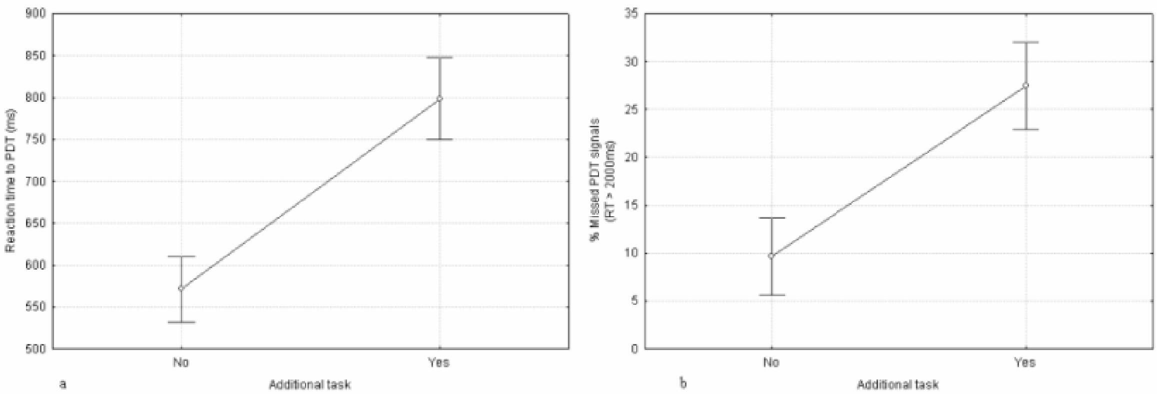

Figure 4: Reaction times to the PDT and percentage of missed PDT signals, both with and without the additional task

5.2 Behavioural reactions to the unexpected events

5.2.1 Effects of event type

The event with the suddenly braking lead car required actions of compensation in the longitudinal direction, braking and lowering driving speed. The accelerating car from the left required a combination of turning away and braking. We expected that the two types of compensation would bring about two different effects on driving behaviour after the events. This was indeed the case. Average speed, for instance, did not show a statistically significant change after the accelerating event ($F(7,231)=1.569$, $p=.143$) but participants did temporarily lower their speed after the braking event as compared to the reference drive ($F(7,231)=3.235$, $p<.005$)
The same effects were seen when looking at minimum speed. Minimum speed before the intersection was lowered temporarily after the braking event ($F(7,231)=2.524$, $p<.025$) but did not differ statistically significant after the accelerating event ($F(7,231)=1.265$, $p=.269$). It appears that the type of compensation required partially determines how driving behaviour after the events is changed.

5.2.2 Effects of workload

It was established in the previous section that the reactions to the two types of events were very different. Therefore, the effects described in the next sections will be related to one specific unexpected event. We will first describe the effects of workload on the reactions to the braking event. Next, the effects of workload on the behavioural reactions to the accelerating vehicle are determined.

An interaction effect of workload and drive (drive with braking event compared to reference drive) on average driving speed was seen after the braking event. Participants without an additional task did not show much difference in average driving speeds between the two drives, but those with higher workload drove significantly slower in the event drive than in the reference drive ($F(1,33)= 4.442$, $p<.050$, see Figure 5a).
There was a strong main effect of workload on headway adaptation in the drive with the braking lead car. Participants with and without high workload showed a similar initial reaction to the braking lead car at one intersection. However, participants with

an additional task normalized their headway directly after this intersection, whereas participants without this additional task increased their headway for a longer period of time ($F(7,217) = 2.2375$, $p < .050$).

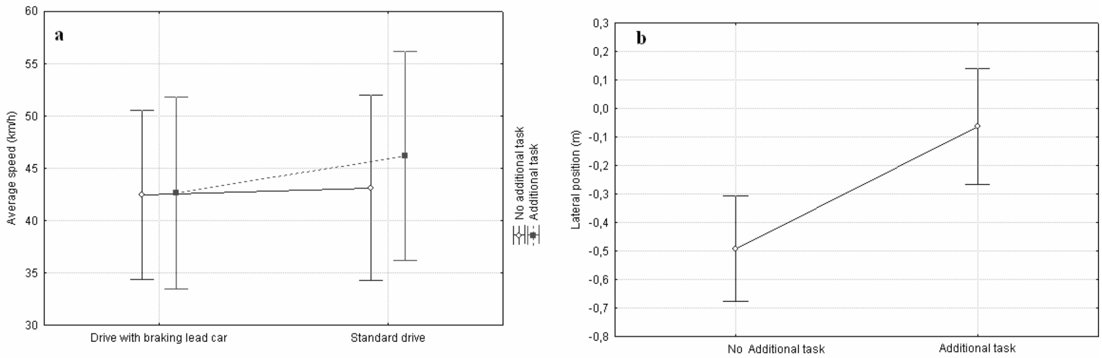

Figure 5: (a) Influence of workload and drive on average speed after the braking event (b) Effect of additional task on lateral position, negative to the right of the middle of the lane

The additional task had one statistically significant effect on driving behaviour after the accelerating event, with the additional task leading to drivers driving more to the outside of the road ($F(1,32)=10.083$, $p<.005$, Figure 5b). The rest of the reactions to the acceleration event was not affected by higher workload.

5.2.3 Effects of event urgency

There was a significant main effect of urgency of the braking event on average driving speed (Figure 6a), although this might be related to the classification of the urgency levels. For participants with less urgent events, average speed was lower than in higher urgency groups ($F(2,33)=5.769$, $p<.010$). The same yields for minimum speed ($F(2,33)=7.144$, $p<.005$).

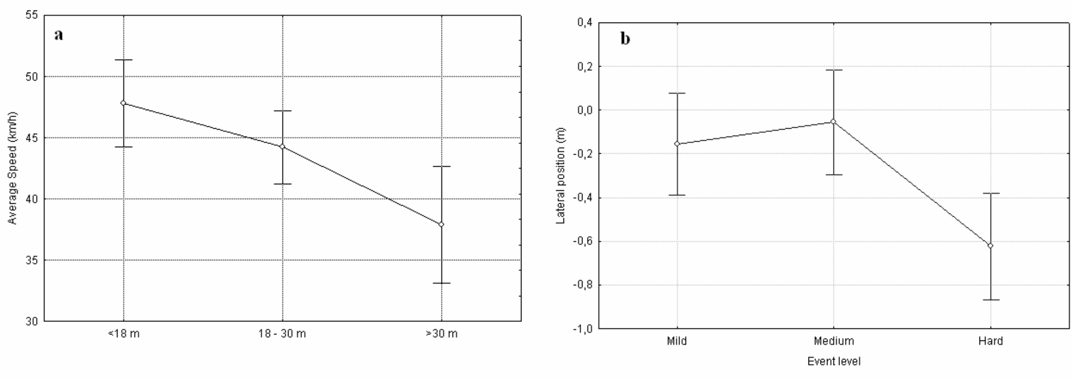

Figure 6: (a) Effect of event urgency on average speed after the braking event; (b) Effect of event urgency on lateral position after the accelerating event, negative to the right of the middle of the lane

An explanation for this could be that participants driving with smaller headways would be classified more often in the more urgent groups.

After the braking event, there was an interaction effect seen between additional workload and urgency of the event on speed pattern. It is clearly visible from Figure 7 that participants with an additional task showed a smoother pattern in approaching speed, except for those with the highest urgency level (Hard), which had a much more profound acceleration curve. The reactions of participants without an additional task did not differ significantly with event urgency, their combined reaction curve is given as the thicker single line in Figure 7.

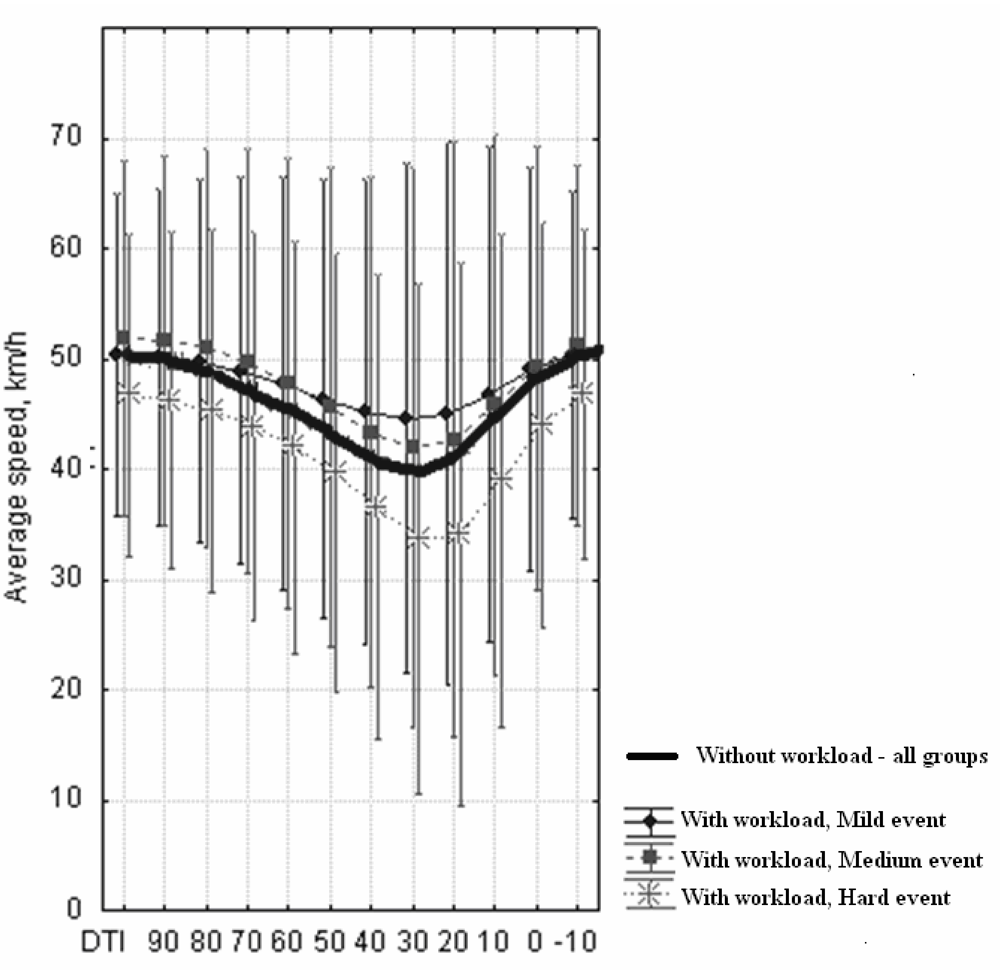

Figure 7: Interaction effect of workload and event urgency on average speed per 10 m Distance To Intersection (DTI)

For the acceleration event, minimum and average speed did not change statistically significant with urgency; $F(2,33)= 2.49$, $p=.099$ for average speed; $F(2,33)= 2.89$, $p=.070$ for minimum speed. However, a trend did become visible: the more urgent the event, the lower the speed in the measured intersections appeared.

Lead distance increased with acceleration urgency, although this change is not significant at the .05 level ($F(2,27)=3.25$, $p=.054$). The only statistically significant effect occurred for lateral position ($F(2,32)=6.607$, $p<.005$, see Figure 6b). This latter result suggests that only the highest event level causes a clear divergence to the right; the other event levels result in minimal changes in lateral position.

5.2.4 Effects of gender

There was no effect found of gender on the reaction to a sudden braking event. Average speed was not influenced by the gender of the driver, and neither were minimum speed, lateral position, lateral acceleration and lead distance ($F(1,35) < 1$ for all variables).
Gender was also not found to have a statistically significant effect on any of the variables after the unexpected accelerating event. Average speed and minimum speed were not affected by gender, and neither were lateral position and lead distance. ($F(1,35) < 1$ for all variables).

There was no one-way interaction effect found with any of the other factors for either of the two events.

6 Discussion and conclusions

Our results are discussed in the light of our four research questions:

- To what extend do different types of unexpected event have an influence on driving after the event?

The change in longitudinal driving behaviour was the most apparent after the braking event, which required only a longitudinal reaction and longitudinal compensation behaviour. The acceleration event required a combination of lateral and longitudinal compensation, and effects of this compensation on either longitudinal or lateral driving behaviour after the event were not found. Apparently, drivers change their driving behaviour temporarily after encountering an unexpected event. However, when the required compensation can not be classified as strictly longitudinal or lateral, the change could possibly not become clear in longitudinal or lateral tasks, as was the case in this study. However, after a closer look at the different urgency levels, it became clear that there indeed was a difference between the effects seen after the most urgent events, as will be discussed next.

- To what extend does the urgency of an unexpected event change the interaction between different subtasks of driving?

The urgency of the braking event changed the way participants reacted to the braking lead vehicle. When the event was more urgent participants drove slower and reach their (lower) minimum speed earlier before the intersection. The urgency of the hardest acceleration event only had an influence on lateral position (participants drove more to the outside after the most urgent acceleration event). So although the acceleration event itself did not change driving behaviour, looking closer at the urgency levels did show an effect, mostly of the hardest acceleration event. It appears that the reaction to an unexpected event is exaggerated with higher urgency levels.

There was also an interaction effect with workload, which will be discussed next.

- To what extend does additional cognitive workload have an effect on the influence between subtasks of driving?

The additional task and thus higher workload had an influence on driving speed: participants with higher workload drove faster in reference drives and showed bigger differences between drives than those without as additional task, especially after the braking event. Headway was also influenced by workload in this scenario: the effect of the braking event lasted shorter for participants with higher workload, and the headway normalized faster after the event.
The overall speed pattern for drivers with an additional task was more smooth (smaller bandwidth of speed values) than for those without the additional task. The effects of the braking event on driving speed were most clear in the high-workload group. The high-workload group with the highest urgency (Hard) had lower speeds and a larger bandwidth of speed values than any of the other groups. On the other hand, the high-workload participants with the mild and medium urgent events showed higher overall speeds and smoother acceleration and deceleration than the group without an additional task. A possible explanation is that drivers with higher workload are more occupied with their additional task and therefore give less attention to the unexpected event. They might generally drive smoother since they react less to certain cues in their environment. However, when the unexpected event reaches a certain threshold, its effect might get through more strongly, leading to a strong change in behaviour. This is also seen in headway effects, where it is clear that participants with an additional task react stronger but shorter to the braking event than participants without an additional task.
Finally, drivers without higher workload tend to drive more to the outside of the road than those with an additional task.

- To what extend does gender have an effect on the influence between subtasks of driving?

Gender does not have any effect on the measured tasks of driving after an unexpected event, nor is there any interaction effect with other situational factors or workload.

Concluding, it is clear that not only the type of event itself but also the urgency of the event and workload level has a significant effect on the reactions to an unexpected event, but gender does not have an effect.

Drivers who are occupied by a secondary task react differently to an unexpected event than drivers who focus solely on their driving task. This is an important result: it supports better understanding of how workload influences the performance of drivers. This might also be an important step in the development of a workload manager which determines in which high-workload situations a driver needs to be relieved from part of his task. ADAS developments can benefit from this knowledge about the structure of the driving task, and the way in which certain factors can influence the manner in which drivers react to events in the traffic system.

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References

Baumann, M. R. K., T. Petzoldt, C. Groenewoud, J. Hogema and J. F. Krems (2008) The effects of cognitive tasks on predicting events in traffic, in *Proceedings of the European conference on Human Centred design for Intelligent Transport Systems*. Lyon, April 3 – 4, 2008.

Brookhuis, K., G. de Vries and D. de Waard (1991) The effects of mobile telephoning on driving performance, *Accident Analysis and Prevention* 23(4), pp. 309 - 316.

Brookhuis, K.A., D. de Waard, W. Janssen (2001) Behavioural impacts of Advanced Driver Assistance Systems – an overview, in *European Journal of Transport and Infrastructure Research* 1(3), pp. 245 – 253.

Brookhuis, K.A., D. de Waard (2005) ADAS' acceptance and effects on behaviour: the consequences of automation? In G. Underwood (Ed.) *Traffic and Transport Psychology. Theory and Application.* Amsterdam: Elsevier, pp. 273-278.

Chisholm, S. L., J. K. Caird and J. Lockhart (2008) The effects of practice with MP3 players on driving performance, *Accident Analysis and Prevention* 40(2), pp. 704 - 713.

De Waard, D. (1996) *The measurement of drivers' mental workload*, Doctoral thesis. University of Groningen, Groningen, The Netherlands.

Dragutinovic, N., K.A. Brookhuis, M. Hagenzieker, and V. Marchau (2005) Behavioural effects of Advanced Cruise Control Use – A meta-analytic approach, in *European Journal of Transport and Infrastructure Research* 5(4), pp. 267 – 280.

Feenstra, P., and J. H. Hogema (2007) Driving simulator assessment for human factors research, in *Proceedings 6th European Congress on ITS*, Aalborg, Denmark, June 2007

Hart, S. G. and L. E. Staveland (1988) Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research, in Hancock, P. A. and N. Meshkati (eds.) *Human Mental Workload,* Amsterdam: North Holland Press, pp. 239-250.

Hole, G. (2007) *The psychology of driving,* London: Lawrence Erlbaum Associates, Publishers, pp. 96 – 98.

Jahn, G., A. Oehme, J. Krems and C. Gelau (2005) Peripheral detection as a workload measure in driving: Effects of traffic complexity and route guidance system use in a driving study, *Transportation Research Part F* 8, pp. 255 – 275.

Michon, J. A. (1971) *Psychonomie onderweg*, Inaugural speech at University of Groningen. November 2, 1971.

Michon, J. A. (1985) A critical view of driver behaviour models: What do we know, what should we do?, in: Evans, L. and R. C. Schwing (eds.) *Human Behaviour and Traffic Safety*, New York: Plenum Press, pp. 485 – 520.

Recarte, M. A. and L. M. Nunes (2003) Mental workload while driving: effects on visual search, discrimination, and decision making, *Journal of Experimental Psychology: Applied* 9(2), pp. 119 – 137.

Schaap, T. W. and B. van Arem (2006) A comprehensive driver behaviour model for the evaluation of intelligent intersections, in *Proceedings of the 13th ITS World Congress*, London, UK, October 2006, Paper 1305.

Schaap, T. W., Van der Horst, A. R. A. and Van Arem, B. (accepted) Explorative analysis of rections to sudden braking at urban intersections under varying workload conditions: towards a driver model for ADAS development. Accepted to *IET Intelligent Transport Journal*.

ST Software (2008) *ST Software Car driving simulator for driver training, assessment and research*, [http://www.stsoftware.nl], accessed May 2008.

SWOV (2008), *Time series based on the previous Accidents and Network product 1976-2007*, [http://www.swov.nl/UK/Research/Kennisbank/inhoud/kennisbank.htm], accessed May 2008.

Van Winsum, W., M. Martens and L. Herland (1999) *The effects of speech versus tactile driver support messages on workload, driver behaviour and user acceptance*, Report TM–01–D009, TNO Human Factors Research Institute, Soesterberg, The Netherlands.

Van Winsum, W. and M. Hoedemaeker (2000) *A road test of a prototype satellite system for in-vehicle menu control*, Report TM–00–C003, TNO Human Factors Research Institute, Soesterberg, The Netherlands.